RM No. A6G24

NACA

RESEARCH MEMORANDUM

THE SUBSONIC AERODYNAMIC CHARACTERISTICS OF TWO DOUBLE-WEDGE AIRFOIL SECTIONS SUITABLE FOR SUPERSONIC FLIGHT

By Joseph Solomon and Floyd W. Henney

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

May 12, 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

THE SUBSONIC AERODYNAMIC CHARACTERISTICS OF TWO DOUBLE-WEDGE AIRFOIL SECTIONS SUITABLE FOR SUPERSONIC FLIGHT

By Joseph Solomon and Floyd W. Henney

SUMMARY

High-speed wind-tunnel tests have been made to investigate the aerodynamic characteristics at subsonic speeds of two symmetrical double-wedge airfoil sections of 4- and 6-percent-chord thickness suitable for application to supersonic aircraft. Section coefficients of lift, drag, and quarter-chord pitching moment are presented for a moderate range of angles of attack at Mach numbers up to approximately 0.93. Comparisons are made between the significant characteristics of the double-wedge airfoils and those of the NACA 65-206 airfoil as an index of the merit of the former at subsonic speeds.

The double-wedge airfoil exhibits no characteristics other than those common to the usual subsonic profile which would contribute to unsteady or uncontrollable flight at subsonic speeds of aircraft employing such a section for lifting surfaces. The lift-curve slope varies with Mach number in a manner similar to that for NACA 65-series airfoils of small thickness. The maximum lift coefficients at low Mach numbers for the double-wedge type of airfoil are comparable to those of uncambered 6-percent-chord-thick NACA airfoils. The drag characteristics of the double-wedge airfoil, while definitely inferior to those of more conventional airfoils at all but the highest test speeds, are such as to permit reasonably satisfactory airplane performance at subsonic speeds. In summary, the test results indicate the definite practicability of the flight at subsonic speeds of aircraft with wings composed of thin airfoil sections of the double-wedge type.

INTRODUCTION

The present widespread acceptance of the concept of practical flight at supersonic speeds has focused increasing attention upon the development of airfoil shapes which will permit sustained flight of aircraft at these speeds. The shapes, and hence the aerodynamic characteristics, of airfoils designed for use at supersonic speeds differ basically from those employed at subsonic speeds. The supersonic airfoil, in practical application, however, must traverse the subsonic speed range in accelerating to supersonic velocities. Any airfoil section suitable for supersonic application must in addition, therefore, permit steady and controllable flight at subsonic and transonic speeds.

The present investigation was undertaken to provide information on the behavior at subsonic speeds of two double-wedge airfoil sections suitable for use at supersonic speeds. Those aerodynamic characteristics which largely determine airplane performance, stability, and control were evaluated for symmetrical double-wedge airfoils having thickness-chord ratios t/c of 0.04 and 0.06 and compared with corresponding characteristics for the NACA 65-206 airfoil section. The latter was chosen as the most satisfactory 6-percent-chord-thick subsonic airfoil section for which comparable data were available. This comparison, made under virtually identical test conditions of Reynolds number, tunnel-wall interference, and instrumentation, afforded a reliable means for evaluating the relative merits at subsonic speeds of the double-wedge airfoil section.

Apparatus and Tests

The tests were performed in the Ames 1- by $3\frac{1}{2}$-foot high-speed wind tunnel, a low-turbulence, two-dimensional flow, closed-throat wind tunnel. Power is supplied by two 1000-horsepower motors in sufficient quantity to achieve the choked-flow condition discussed in reference 1.

Two doubly symmetrical double-wedge airfoils having thicknesses of 4 and 6 percent of the chord were constructed of steel for the tests. A sketch of the double-wedge sections together with the NACA 65-206 profile appears in figure 1. A photograph of an actual model is given in figure 2. The airfoils were of 6-inch chord and were mounted as shown in figure 3 so as to span completely the 1-foot width of the tunnel test section. Two-dimensional-flow conditions were achieved through the prevention of end leakage about the airfoil by means of rubber gaskets compressed between the model ends and the tunnel side walls.

Measurements of lift, drag, and quarter-chord pitching moment were made simultaneously for angles of attack from 0° to 10° at Mach numbers from 0.30 to approximately 0.93, the tunnel choking speed for the models tested. The Reynolds numbers corresponding to these Mach numbers ranged from approximately 1×10^6 to nearly 2×10^6.

Airfoil lift and pitching moment were determined from measurements of the reactions on the tunnel walls of the forces on the airfoil. Very satisfactory agreement has been demonstrated in previous tests between lift and moment characteristics determined by this method and the corresponding characteristics integrated from simultaneously observed pressure distributions. Drag was determined from wake-survey measurements made with a movable rake of total head tubes.

TEST RESULTS

Section lift, drag, and quarter-chord pitching-moment coefficients for the 4- and 6-percent-chord double-wedge airfoils are presented in figures 4 to 6 and 7 to 9, respectively, as functions of Mach number for constant angles of attack. Corresponding characteristics for the NACA 65-206 airfoil section are given in figures 10 to 12. Cross plots at constant Mach number showing the variation of section lift coefficient with angle of attack, and of section drag and pitching-moment coefficients with section lift coefficient for all three airfoils appear in figures 13 to 21. The apparent failure in the cases of the double-wedge airfoils to realize zero lift and zero pitching moment at zero incidence throughout the entire Mach number range is attributed to two factors. First, the airfoils were not exactly symmetrical about both the chord line and the midchord axis. Second, the method of lift and pitching-moment measurement involves the application of substantial tare corrections to the measured data. Hence at very low angles of attack, where the indicated forces on the airfoils are of the same order of magnitude as the tare corrections, small errors may be introduced in reducing the measured data to the actual airfoil characteristics. All data have been corrected for tunnel-wall interference by the methods of reference 1. The broken lines noted in the curves of figures 4 to 21 are used to indicate that data obtained in the vicinity of the wind-tunnel choking velocity are not considered reliable.

A measure of the relative merit of the double-wedge airfoil at high subsonic speeds is given in figures 22 and 23 which depict the variation of the respective lift- and drag-divergence Mach numbers with section lift coefficient. For comparative purposes the divergence velocities for the NACA 65-206 airfoil are also shown in figures 22 and 23. The Mach number of lift divergence is defined as the value of the Mach number corresponding to the inflection point immediately preceding the major peak on the curve of lift coefficient against Mach number. The drag-divergence velocity is the Mach number at which the final rapid rise in drag coefficient begins.

DISCUSSION

Lift Characteristics

The variation of section lift coefficient with Mach number, shown in figures 4 and 7 for the double-wedge airfoils, appears to be very similar to that for more conventional airfoil sections as exemplified by the NACA 65-206 profile in figure 10. Lift for the double-wedge airfoils is in fact maintained to Mach numbers as high as those for the NACA 65-206 airfoil albeit the lift-divergence Mach numbers, as defined herein and presented in figure 22 for the airfoils under consideration, would not appear to fully support this contention.

Lift divergence, as might be expected, is postponed to somewhat higher Mach numbers for the 4-percent-chord thick airfoil than for the 6-percent-chord thick section.

A particularly significant characteristic of airfoil sections is the slope of the lift curve because it is one of the principal factors affecting airplane stability and control. In figure 24 the variation in lift-curve slope with Mach number for the double-wedge airfoils is seen to be similar to that for the NACA 65-206 airfoil. The low-speed value of lift-curve slope corresponds to the usual value of approximately 0.1 (per degree) for airfoils. At high Mach numbers the effect of thickness on the slope appears to be the same for the double-wedge airfoils as that which has been noted elsewhere for other type airfoils. Changes in stability at transonic speeds, as influenced by variations in lift-curve slope, would seem, then, to be no more severe for aircraft employing double-wedge airfoil sections as lifting surfaces than for those employing more conventional sections.

The maximum lift characteristics of the symmetrical double-wedge airfoils are seen from figure 25 to be inferior to those of the NACA 65-206 section. This observation is not as significant as would first appear in view of the evidence presented in reference 2 demonstrating that, for Reynolds numbers from 3×10^6 to 9×10^6, the maximum lift coefficients of all NACA 6-percent-chord-thick symmetrical airfoil sections have values in the neighborhood of 0.83. The addition of camber appears, from this reference, to result in an increase in the maximum lift coefficient by an amount approximately equal to the design lift coefficient. The low-speed (0.3 Mach number) value of maximum lift coefficient of approximately 0.82 for the 6-percent-chord-thick double-wedge airfoil would appear to indicate that the thin double-wedge airfoils are as satisfactory as other types of airfoils of comparable thickness as far as maximum lift is concerned.

Drag Characteristics

The variation in section drag coefficient with Mach number shown in figures 5 and 8 for the double-wedge airfoils is similar to that for subsonic airfoil sections (cf. fig. 11 for the NACA 65-206 airfoil). Although for a given lift coefficient the drag coefficients for the double-wedge sections are considerably in excess of those for the NACA 65-series airfoils over most of the speed range investigated, the drag curves for the former rise less steeply with Mach number beyond the drag-divergence velocity. This characteristic is more clearly illustrated in figure 26 which depicts the variation in section drag coefficient with Mach number at a lift coefficient of 0.1 for both the double-wedge airfoils and the NACA 65-206 airfoil. From this figure a reduction in thickness of the double-wedge profile is seen to result in a more gradual drag increase with Mach number above the drag-divergence velocity.

In figure 23 it may be seen that the Mach numbers of drag divergence for the double-wedge airfoil are very much lower than those for the NACA 65-series airfoil of comparable thickness, probably because of the abrupt change in contour at the midchord position of the former.

Pitching-Moment Characteristics

Figures 6 and 9 indicate little variation in pitching-moment coefficient with Mach number at small angles of attack for the double-wedge airfoils. This characteristic is more strikingly demonstrated in figure 27 where the variation in pitching-moment coefficient with Mach number is shown for both the double wedges and the NACA 65-206 airfoil at a lift coefficient of 0.1. From this figure it may be noted that the variation is much less for the double-wedge airfoils than for the NACA 65-206 airfoil. This difference in variation can probably be attributed to the amount of camber rather than to the particular airfoil shape.

The variation in pitching-moment coefficient with lift coefficient, which appears in figures 15 and 18, respectively, for the 4- and 6-percent double wedges at various Mach numbers, is such as to exert a mildly stabilizing effect upon an airplane. At very high Mach numbers this stabilizing influence becomes increasingly severe.

CONCLUSIONS

From the results of tests at subsonic speeds of two double-wedge airfoil sections suitable for use at supersonic speeds the following significant conclusions are drawn:

1. The double-wedge airfoil of small thickness exhibits no characteristics peculiar to its type which would prohibit its use as a lifting surface on aircraft operating in the subsonic speed range.

2. The slopes of the lift curves for the double-wedge airfoils at low speeds correspond to the usual value of approximately 0.1 (per degree) for airfoil sections.

3. The low-speed maximum lift coefficients of the double-wedge airfoils investigated are sensibly the same as those of uncambered NACA airfoils of comparable thickness.

4. The drag characteristics of the double-wedge airfoils are inferior except at very high Mach numbers to those of the NACA 65-206 airfoil, a representative thin subsonic profile. At speeds somewhat above those corresponding to drag divergence, the drag rises less steeply with Mach number for the former.

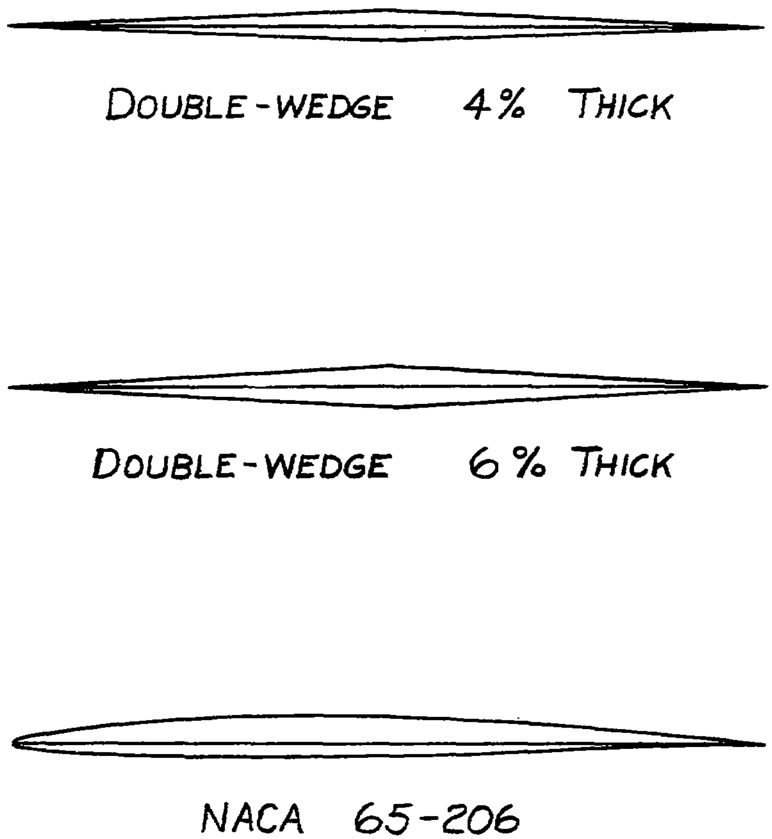
5. At low lift coefficients the variation in pitching-moment coefficient with Mach number for the double-wedge airfoils is regular and small.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. Allen, H. Julian, and Vincenti, Walter G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel with Consideration of the Effect of Compressibility. NACA ARR No. 4K03, 1944.

2. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.



NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

FIGURE 1.- COMPARISON OF AIRFOIL PROFILES.

[redacted]

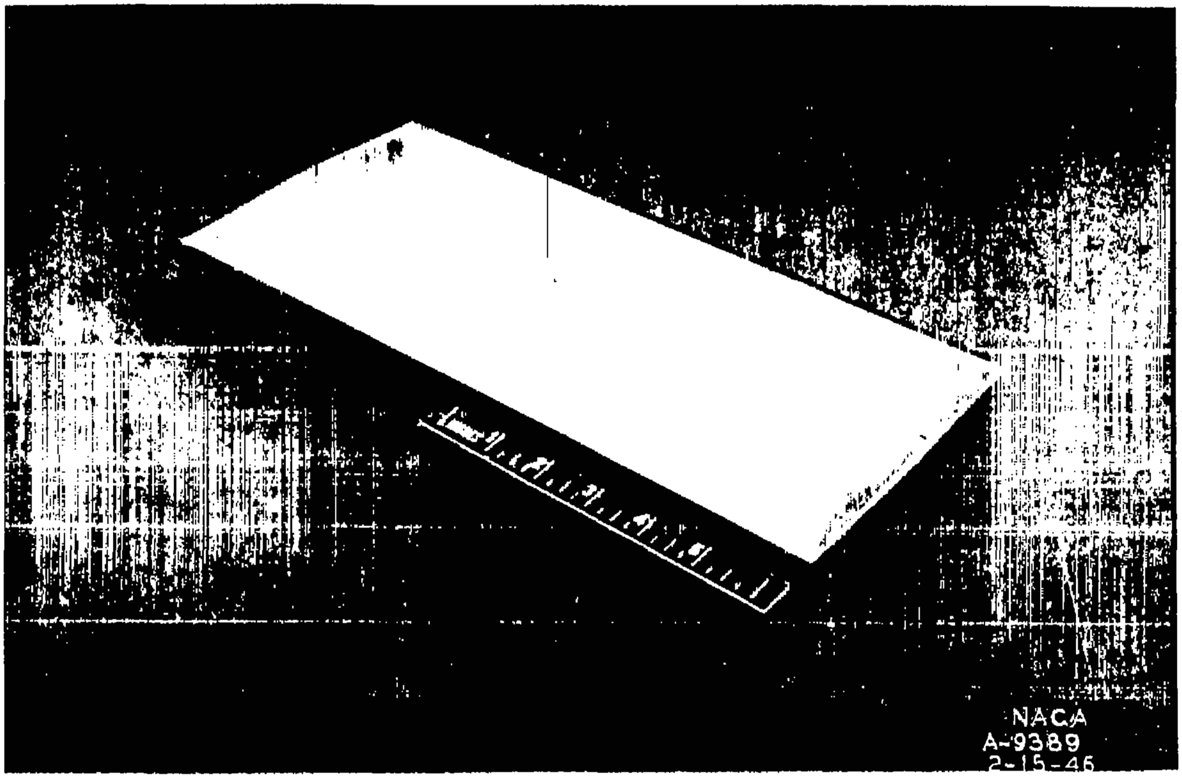


Figure 2.- Model of the symmetrical 4-percent-chord-thick double-wedge airfoil.

Figure 3.- Airfoil model mounted in the test section of the 1 by 3 1/2-foot high-speed wind tunnel.

M-1

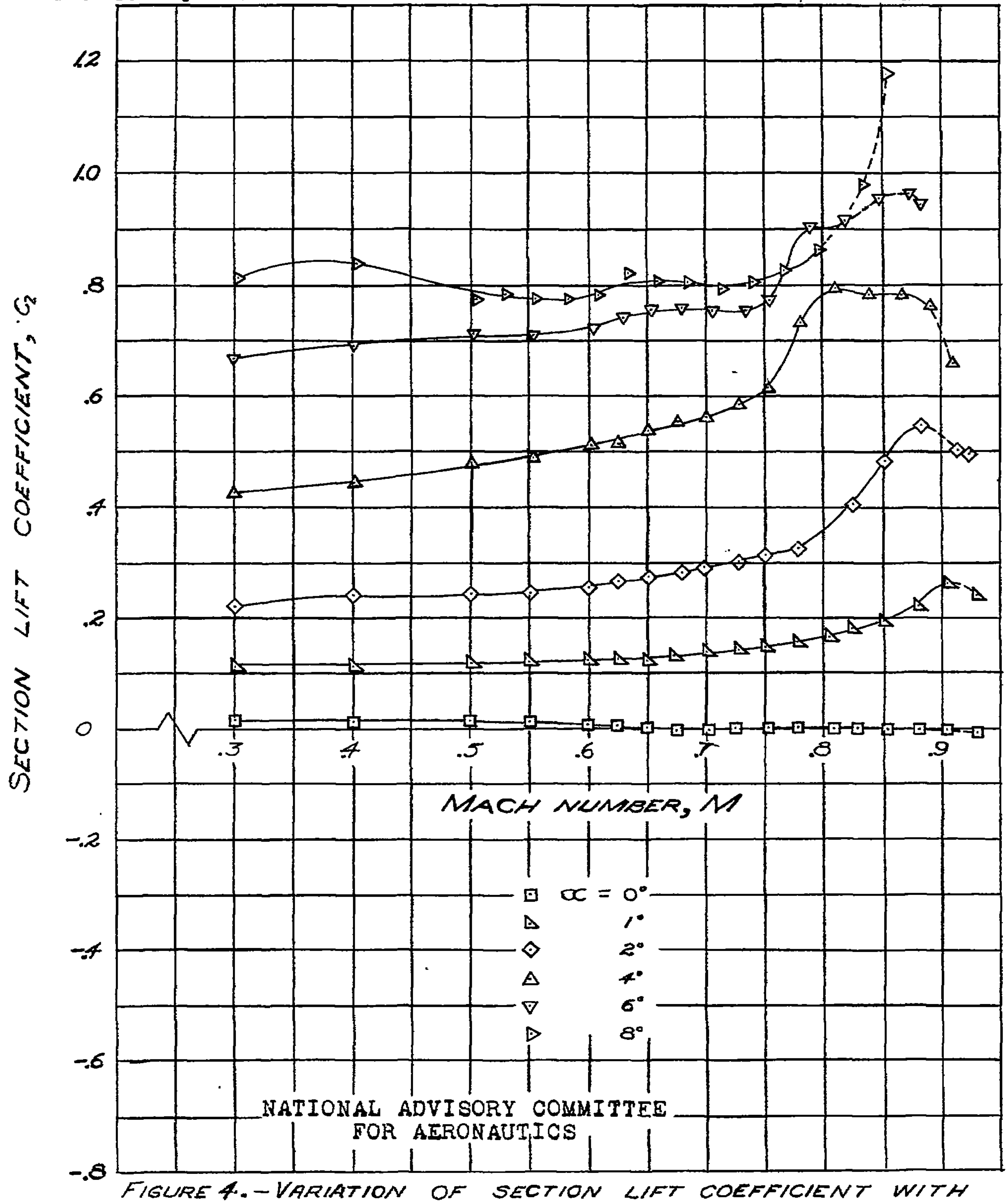


FIGURE 4.—VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c=0.04.

[redacted]

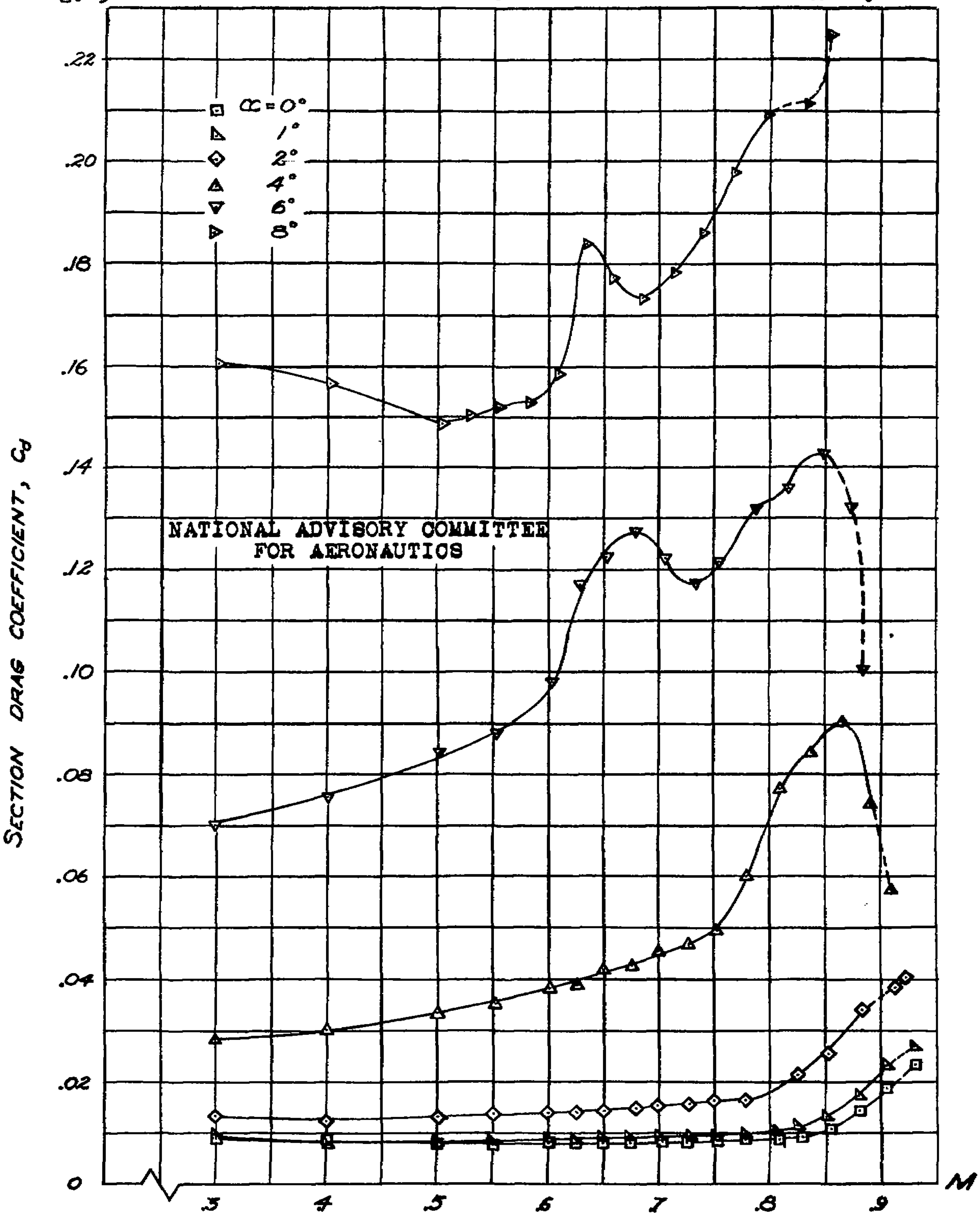


FIGURE 5. — VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL. t/c=0.04.

[redacted]

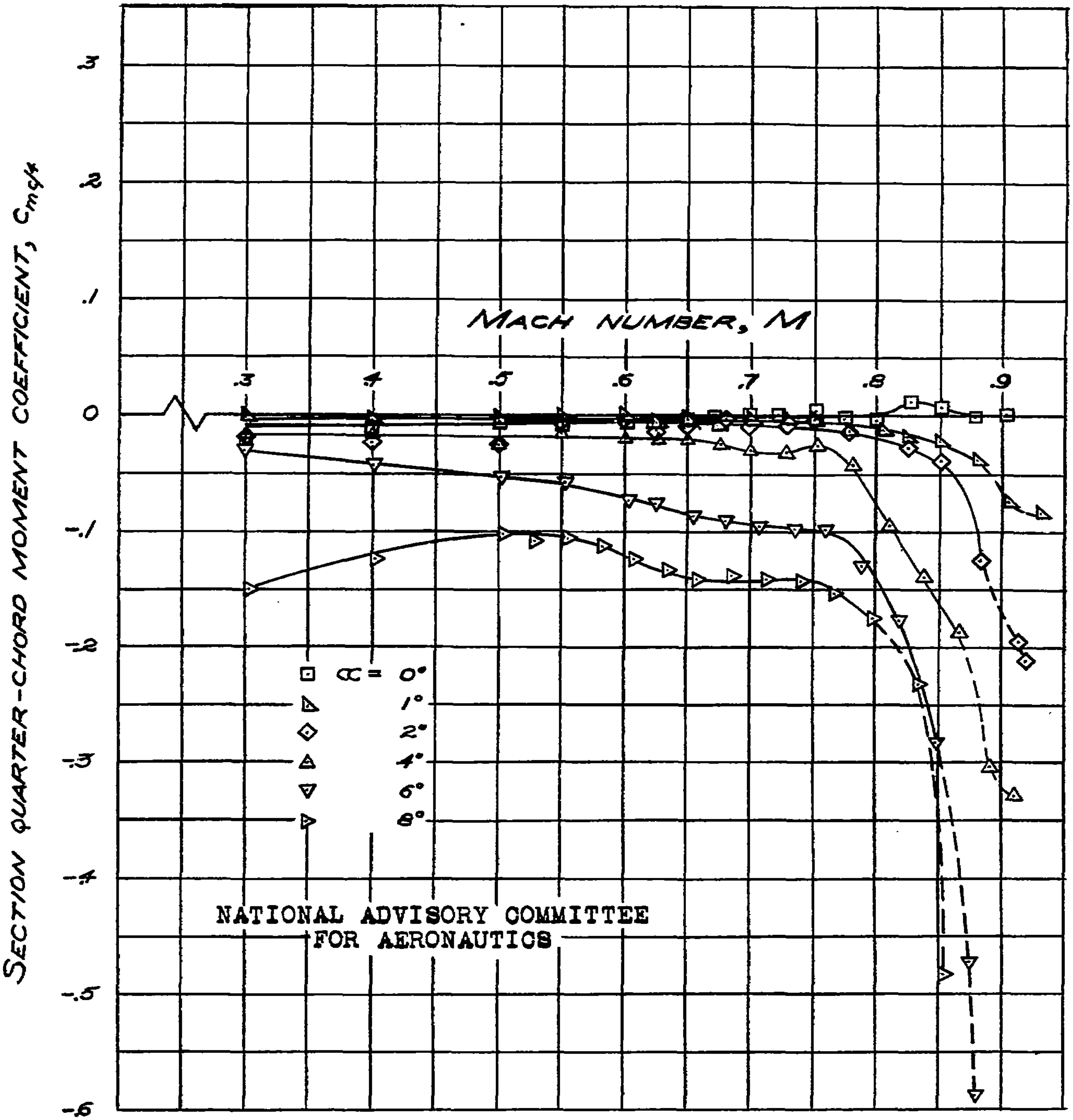


FIGURE 6.- VARIATION OF SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c = 0.04.

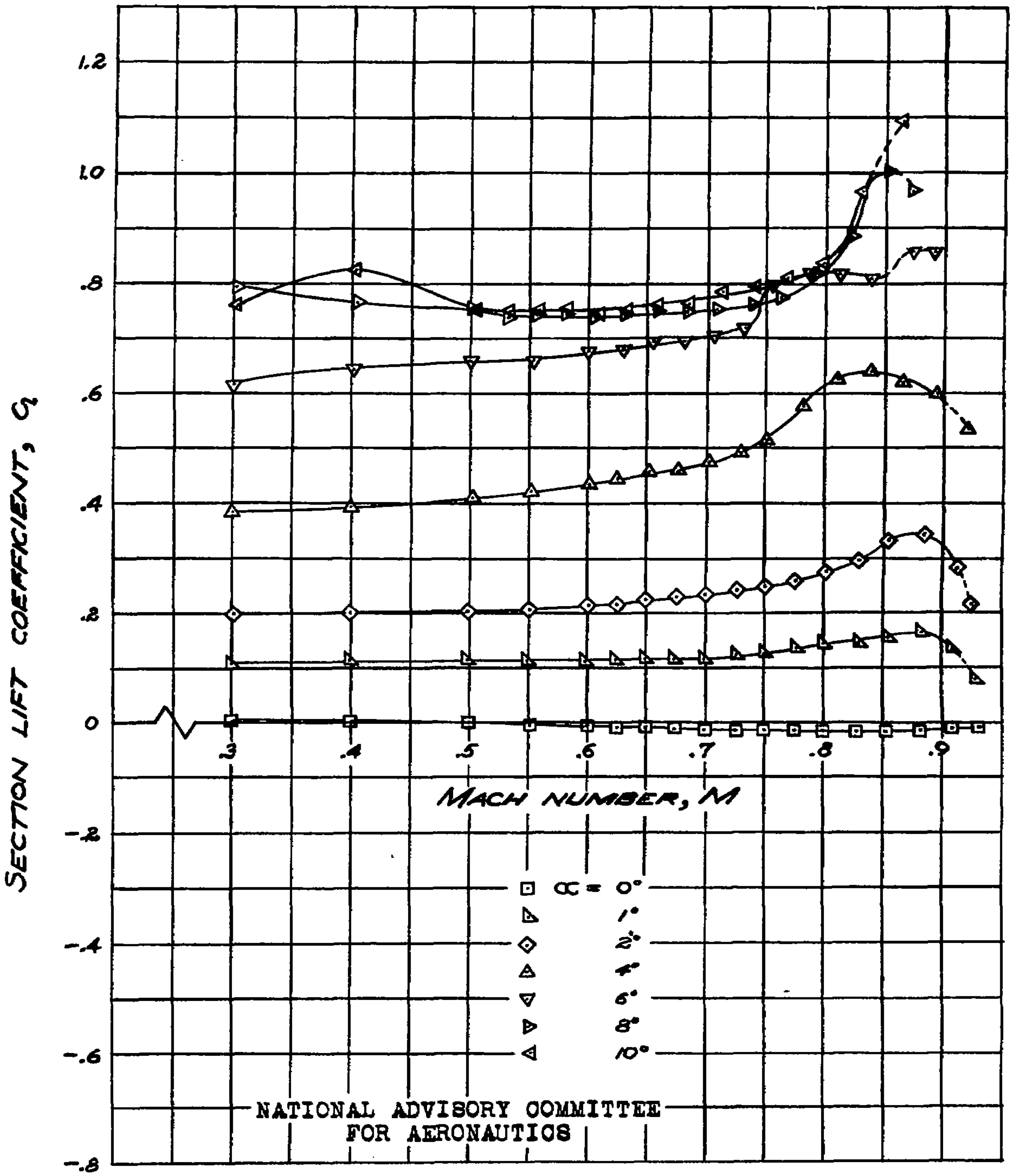


FIGURE 7. — VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, $t/c = 0.06$.

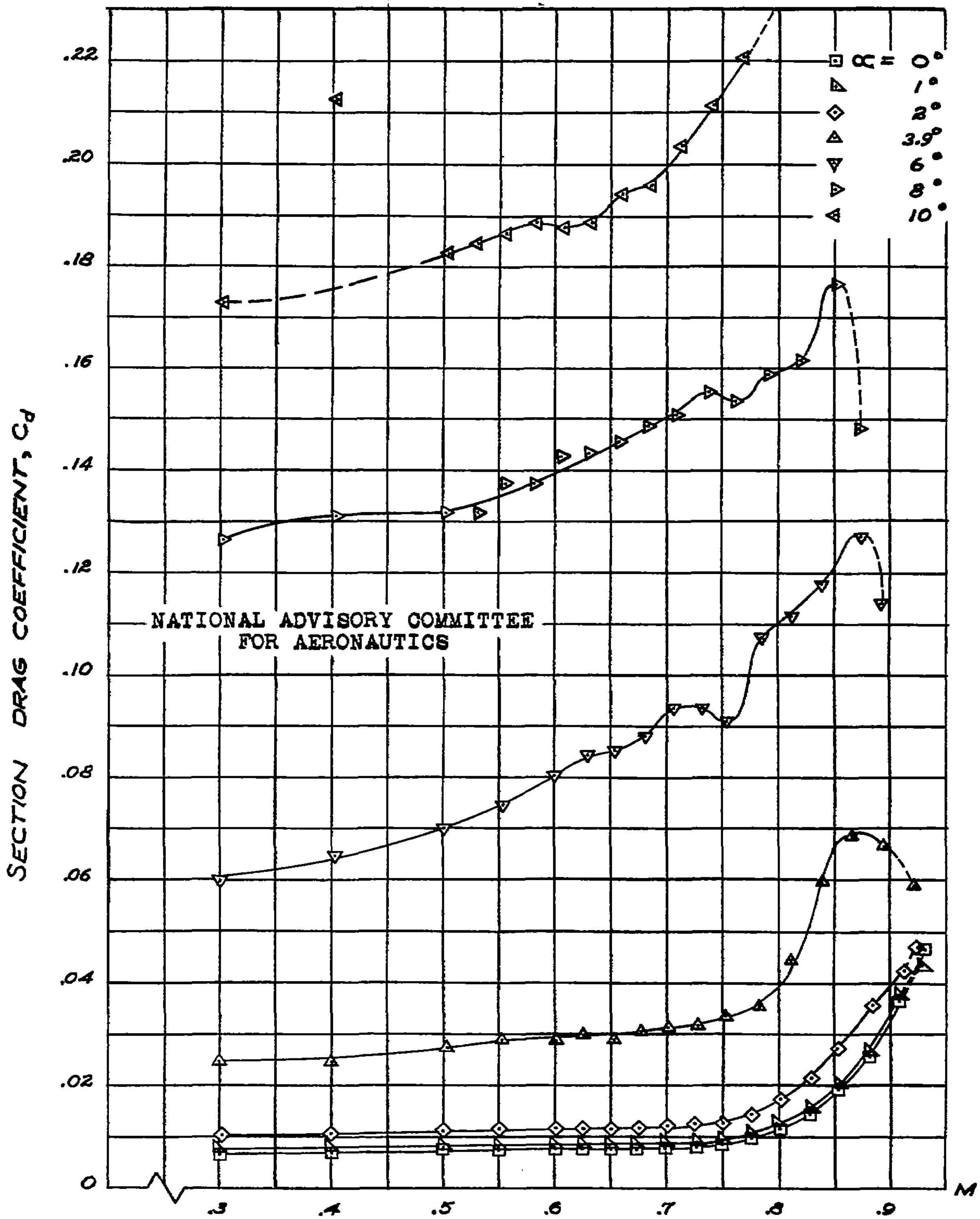


FIGURE 8.—VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE WEDGE AIRFOIL, t/c = 0.06.

[redacted]

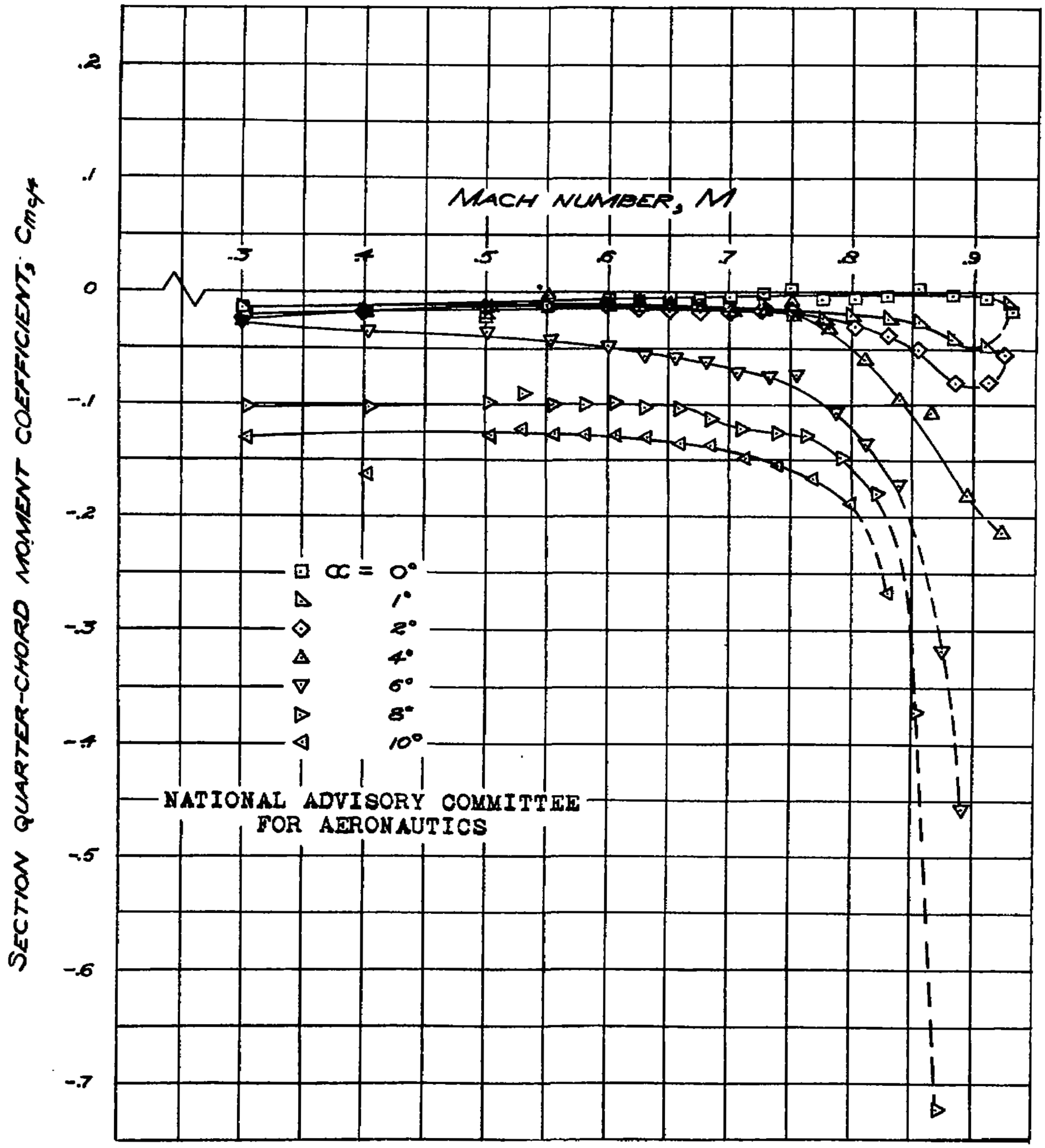


FIGURE 9.-VARIATION OF SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH MACH NUMBER FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c=0.06.

[redacted]

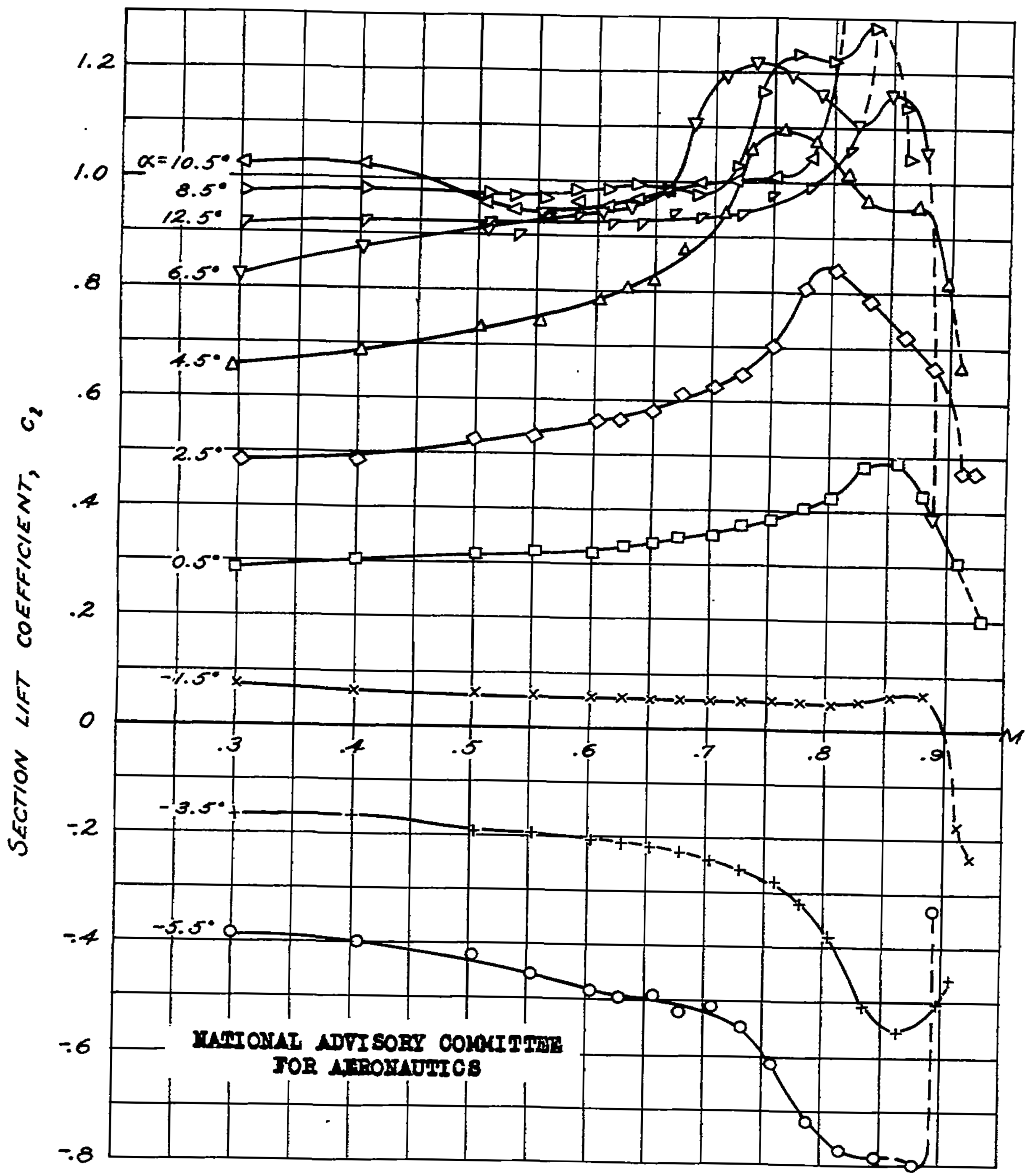


FIGURE 10.— VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR THE NACA 65-206 AIRFOIL.

[redacted]

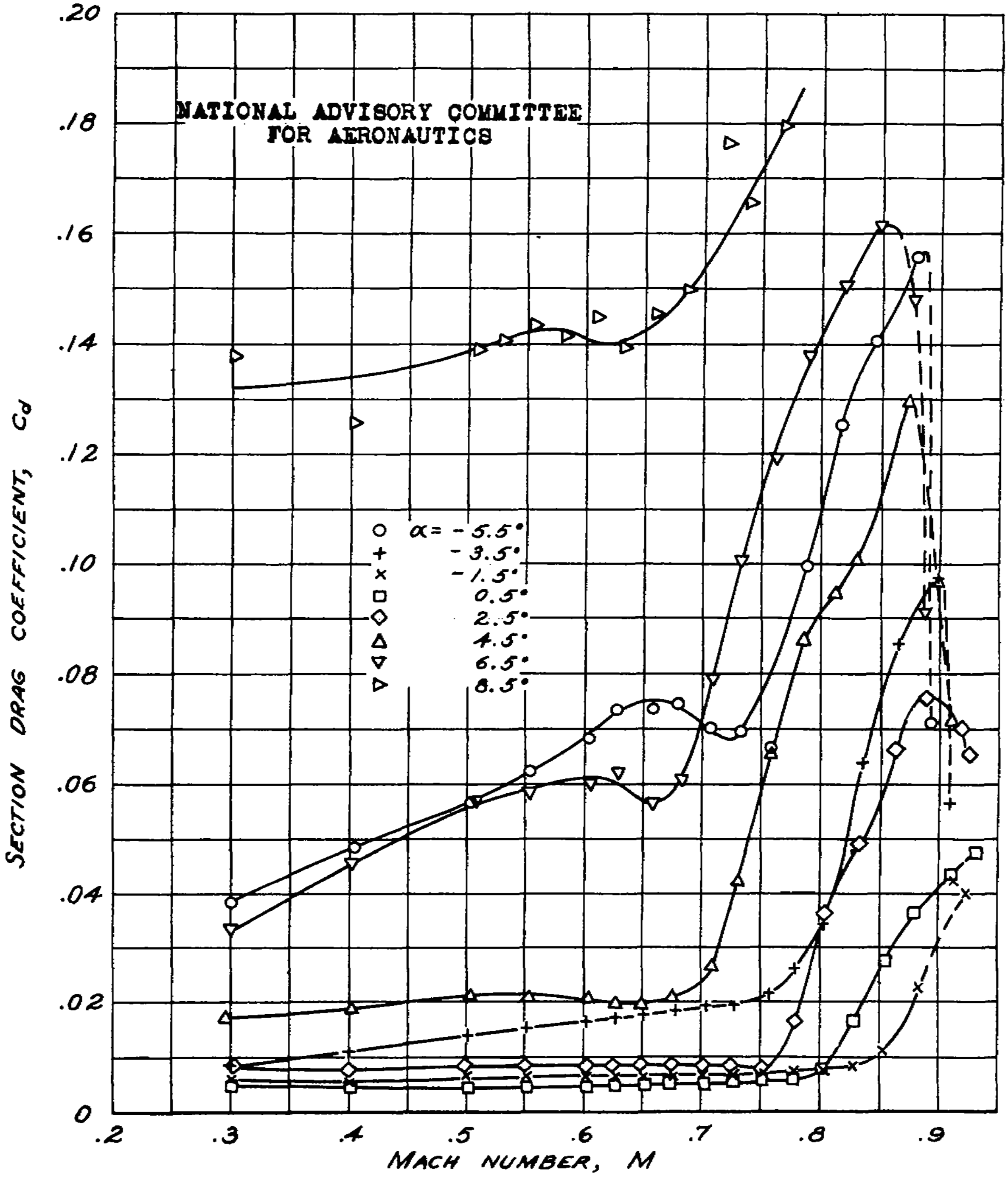


FIGURE 11.– VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR THE NACA 65-206 AIRFOIL.

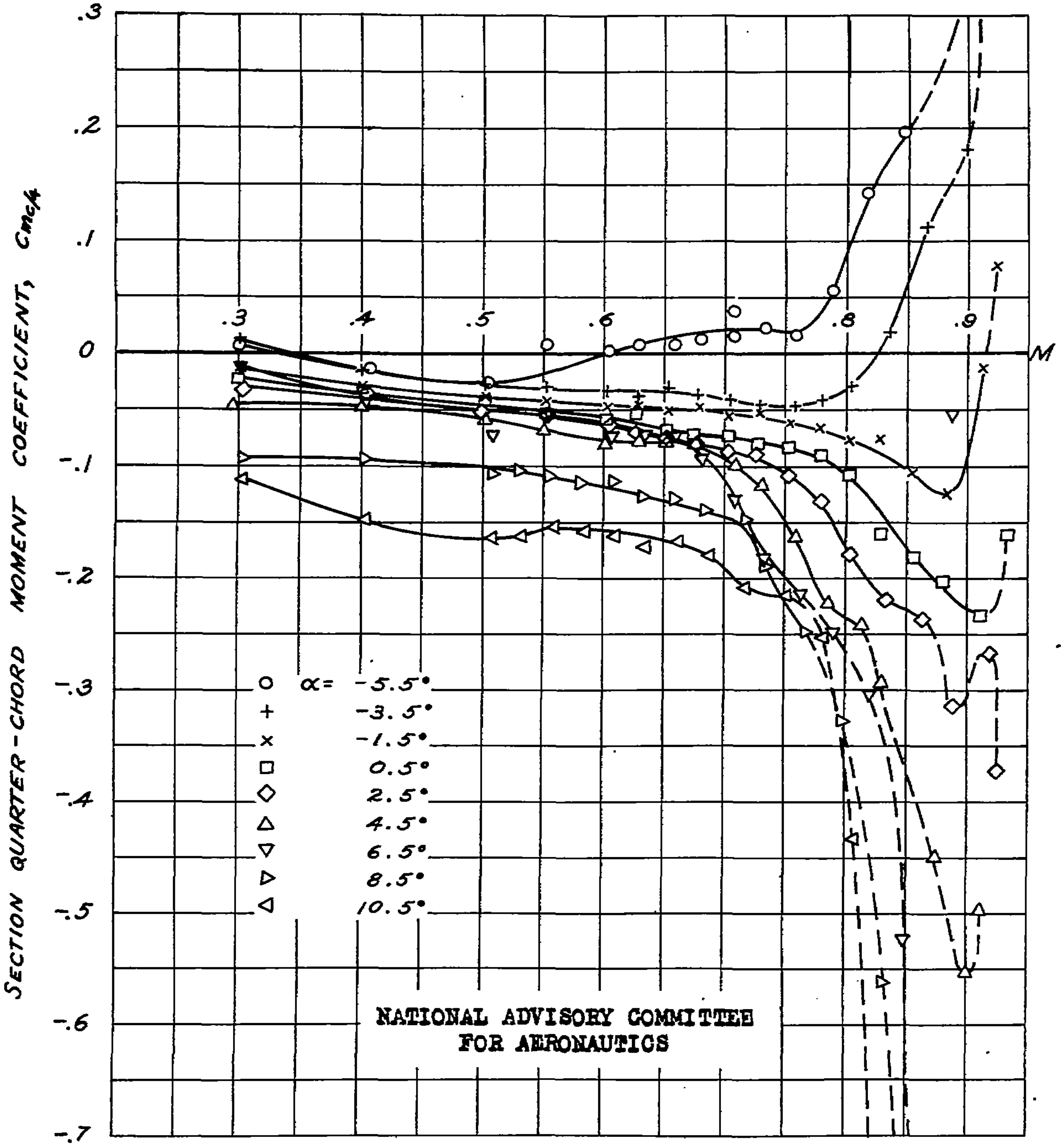


FIGURE 12.— VARIATION OF SECTION MOMENT COEFFICIENT WITH MACH NUMBER FOR THE NACA 65-206 AIRFOIL.

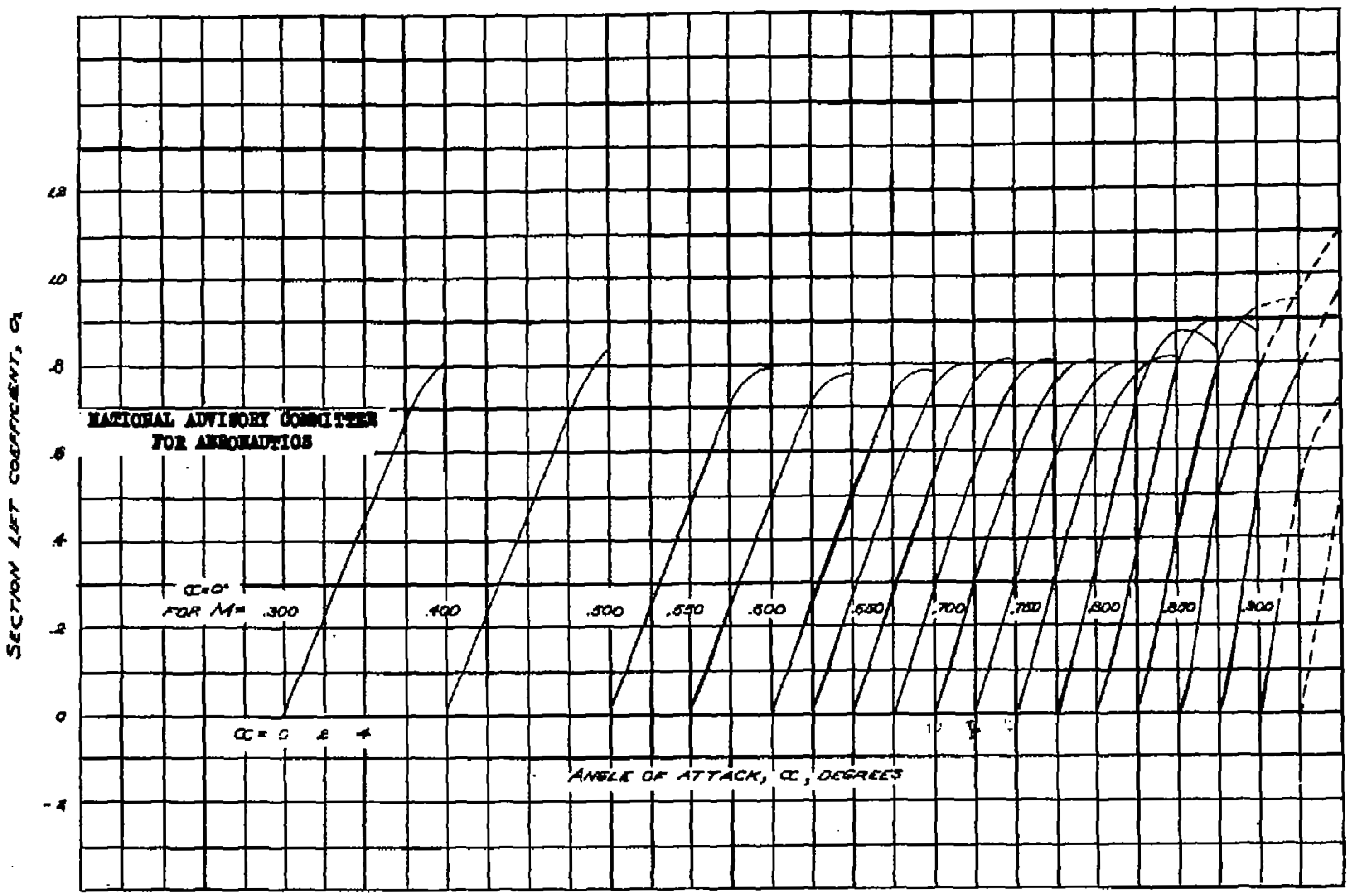


FIGURE 13.- VARIATION OF SECTION LIFT COEFFICIENT WITH ANGLE OF ATTACK FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c=0.04.

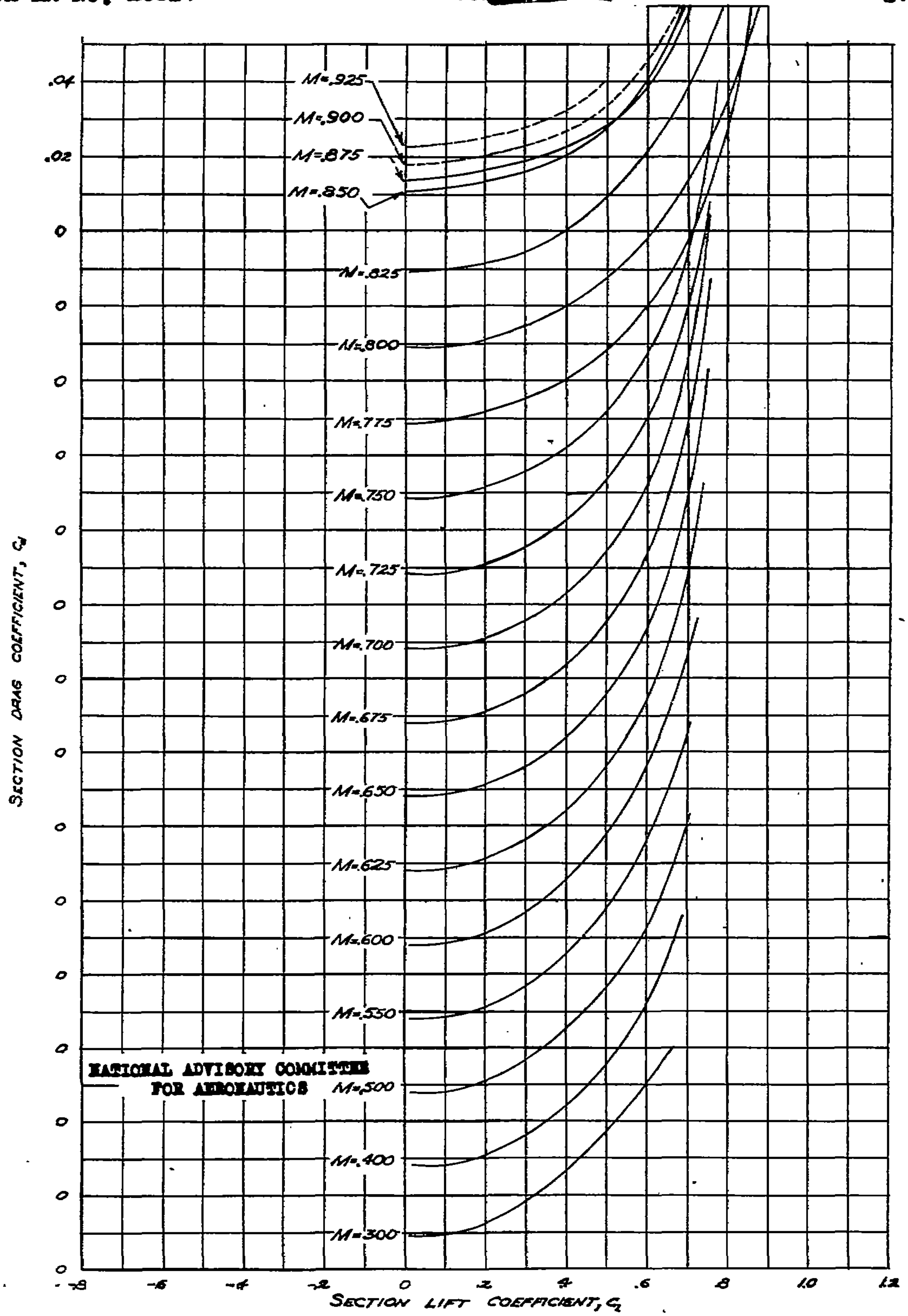


FIGURE 14.—VARIATION OF SECTION DRAG COEFFICIENT WITH LIFT COEFFICIENT FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, $t/c=0.04$.

[redacted]

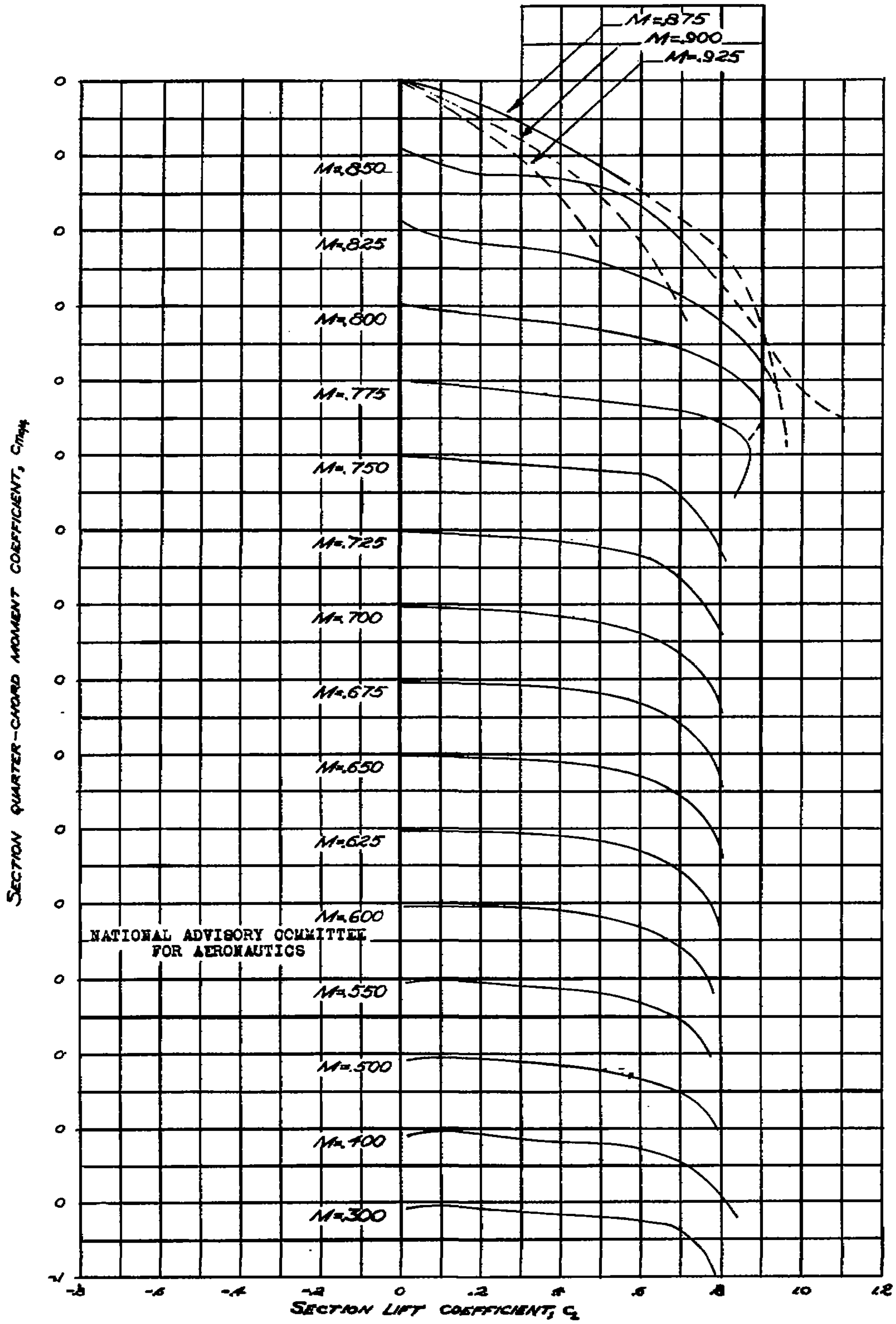


FIGURE 15.- VARIATION OF SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH LIFT COEFFICIENT FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c=0.04.

[redacted]

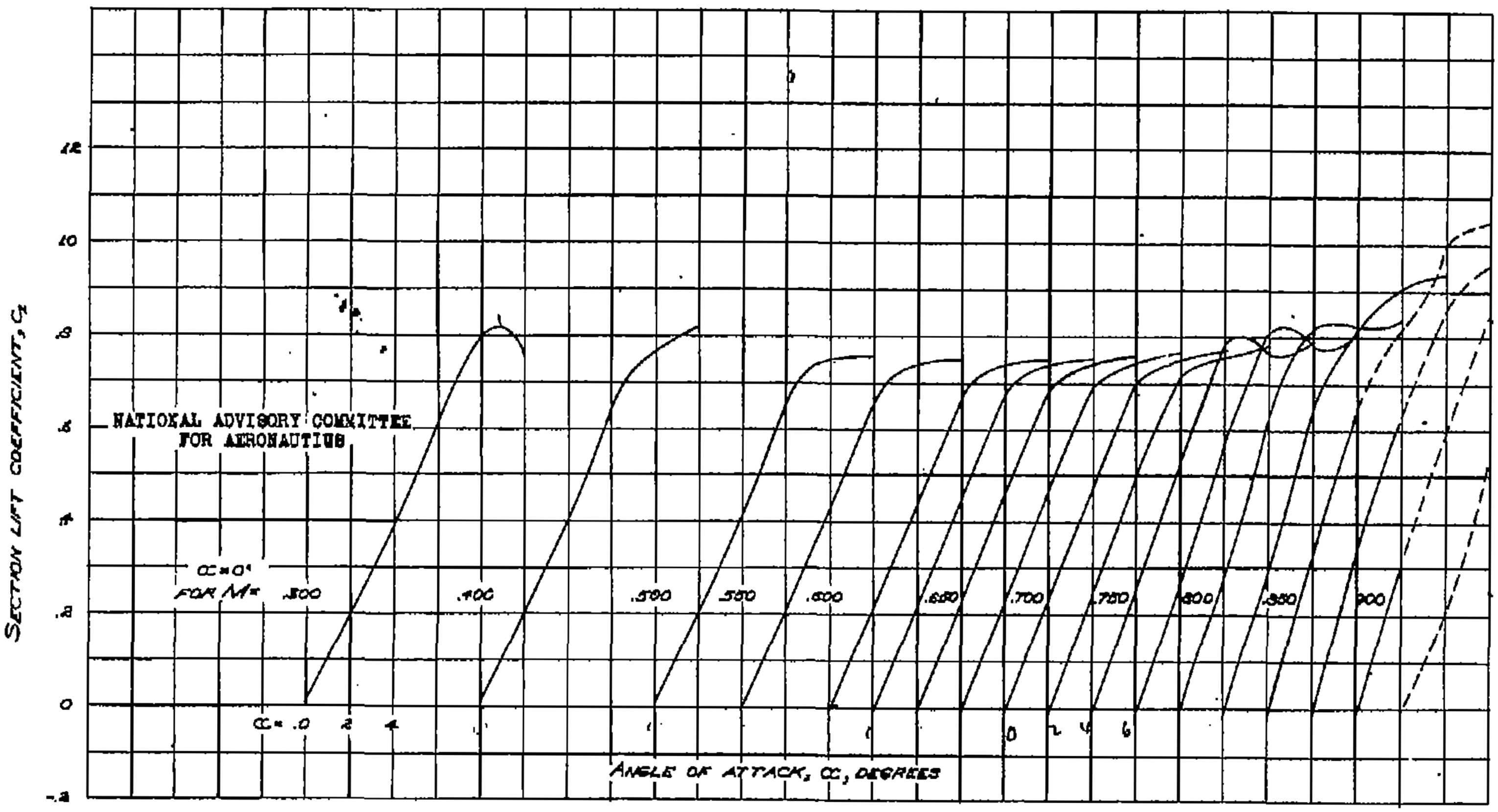


Figure 16.-Variation of section lift coefficient with angle of attack for a symmetrical double-wedge airfoil, $t/c = 0.06$.

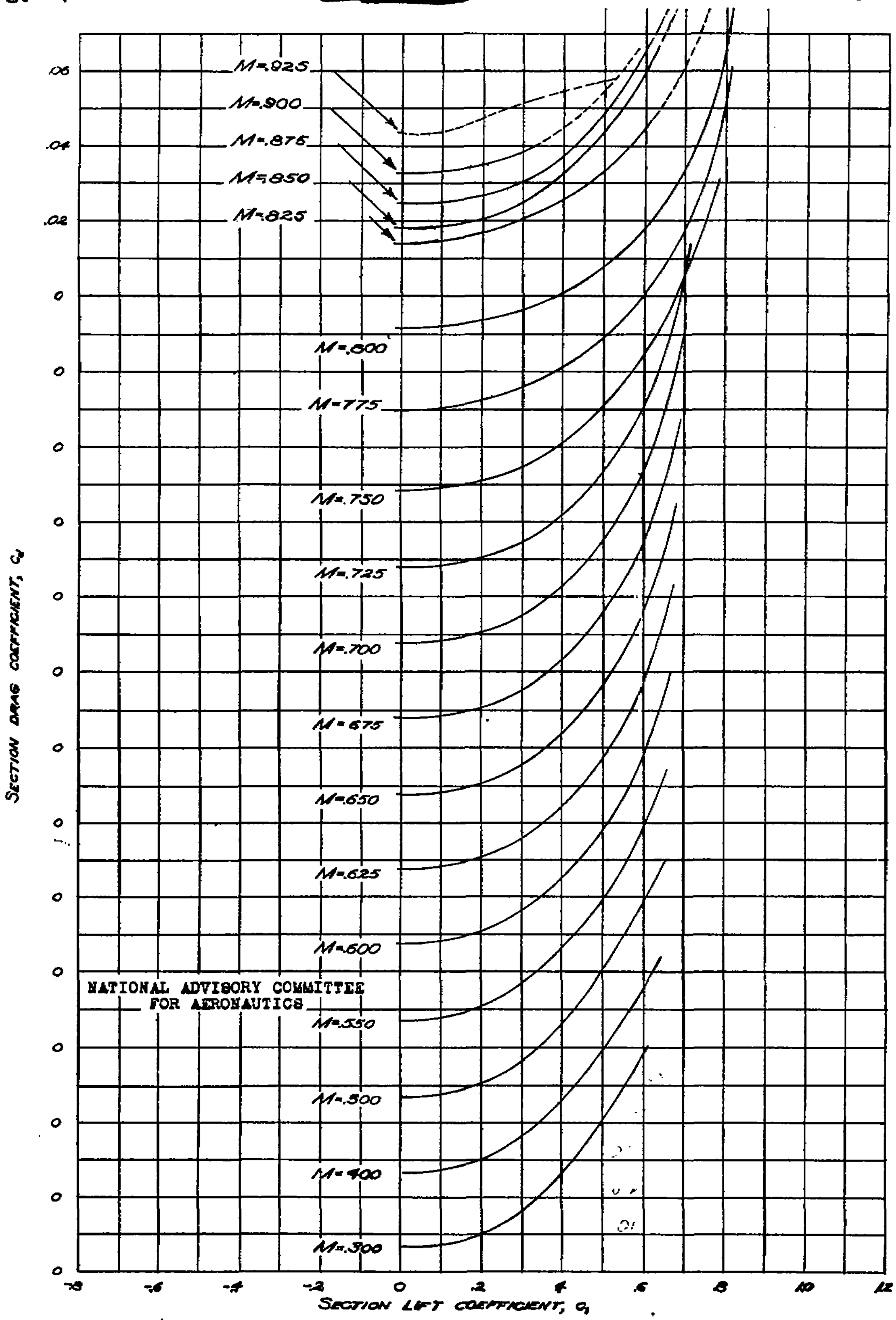


FIGURE 17.- VARIATION OF SECTION DRAG COEFFICIENT WITH LIFT COEFFICIENT FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c=0.06.

[redacted]

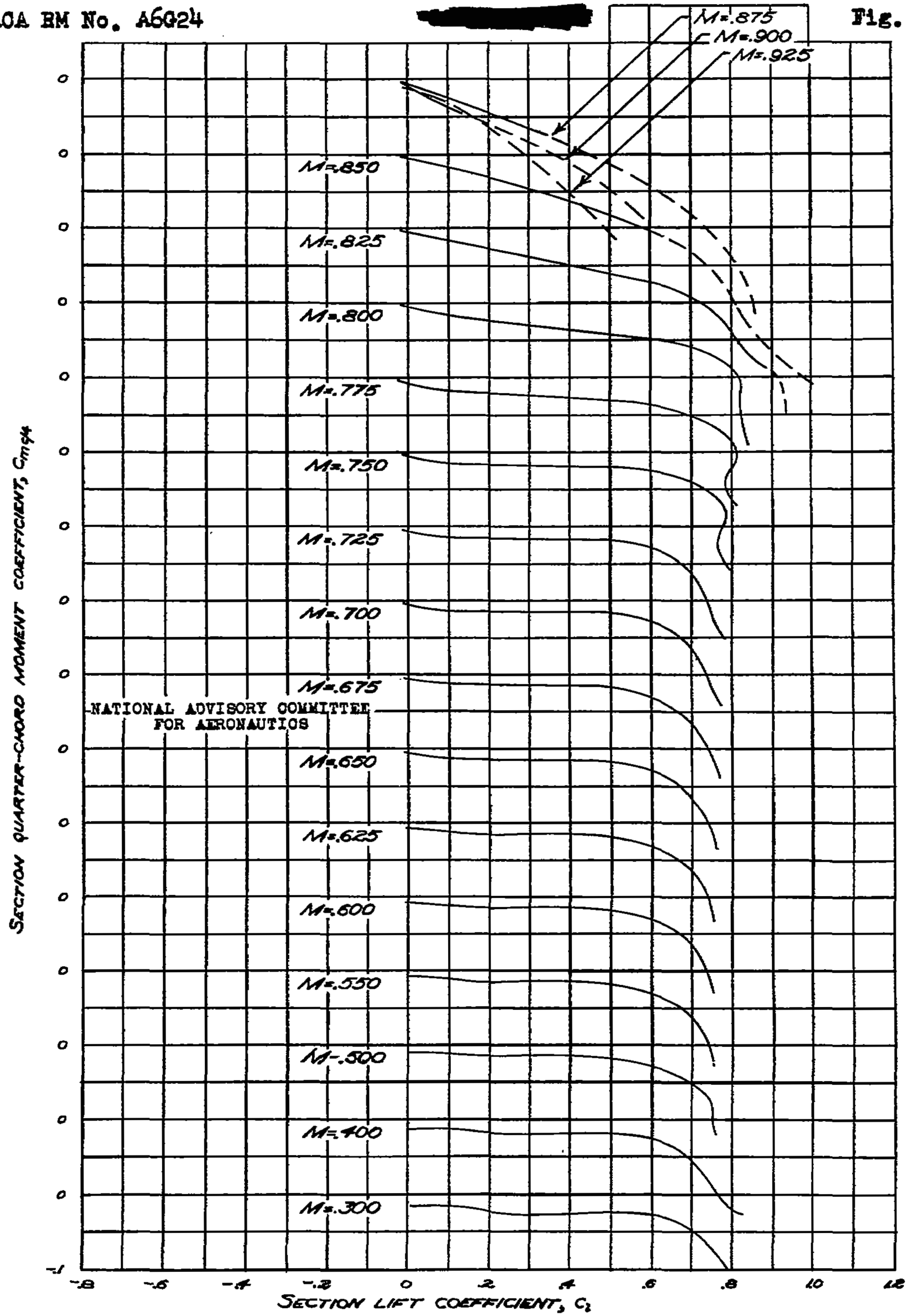


FIGURE 18.-VARIATION OF SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH LIFT COEFFICIENT FOR A SYMMETRICAL DOUBLE-WEDGE AIRFOIL, t/c = 0.06.

[redacted]

[redacted]

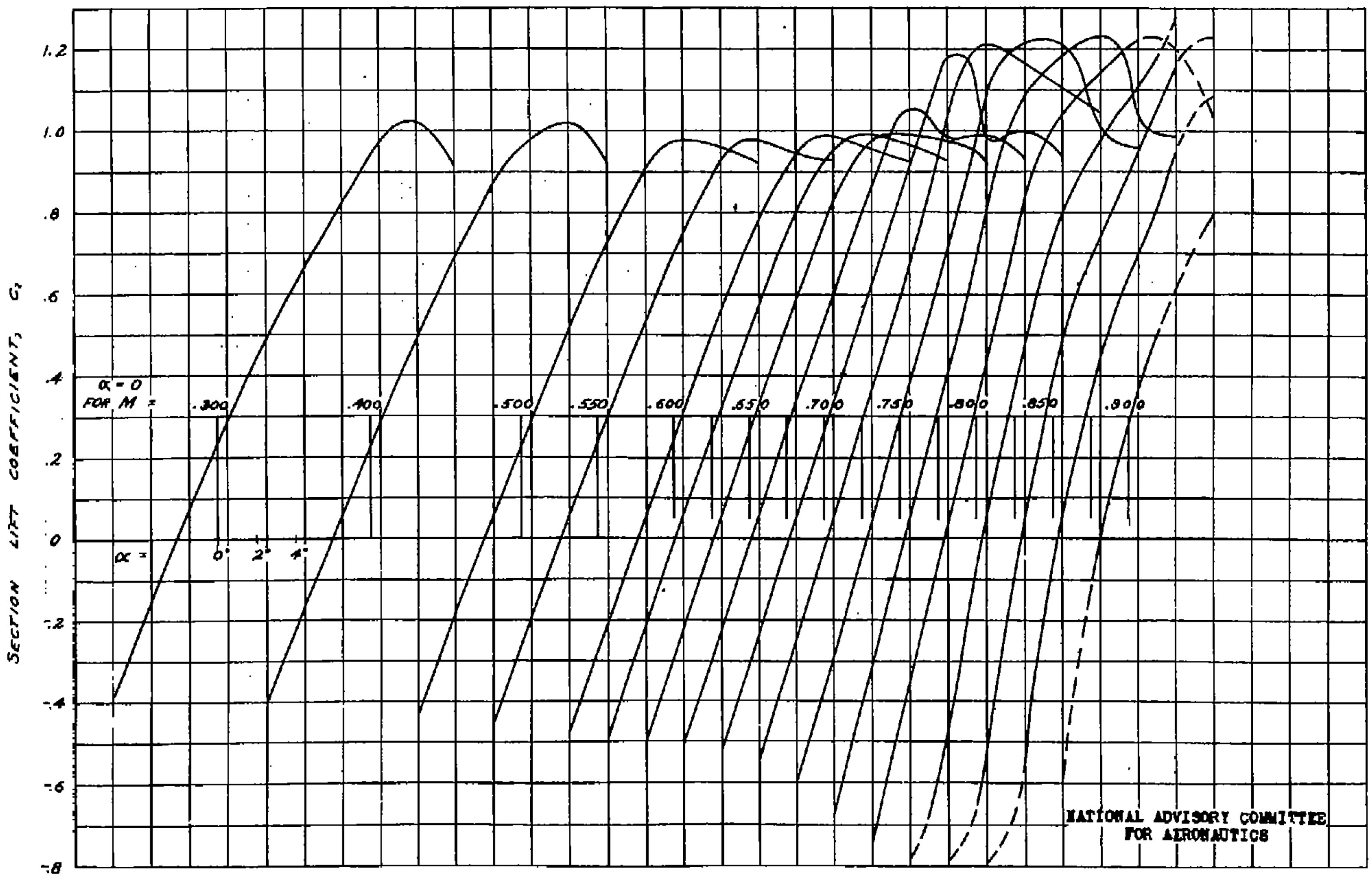


FIGURE 19.- VARIATION OF SECTION LIFT COEFFICIENT WITH ANGLE OF ATTACK FOR THE NACA 65-206 AIRFOIL.

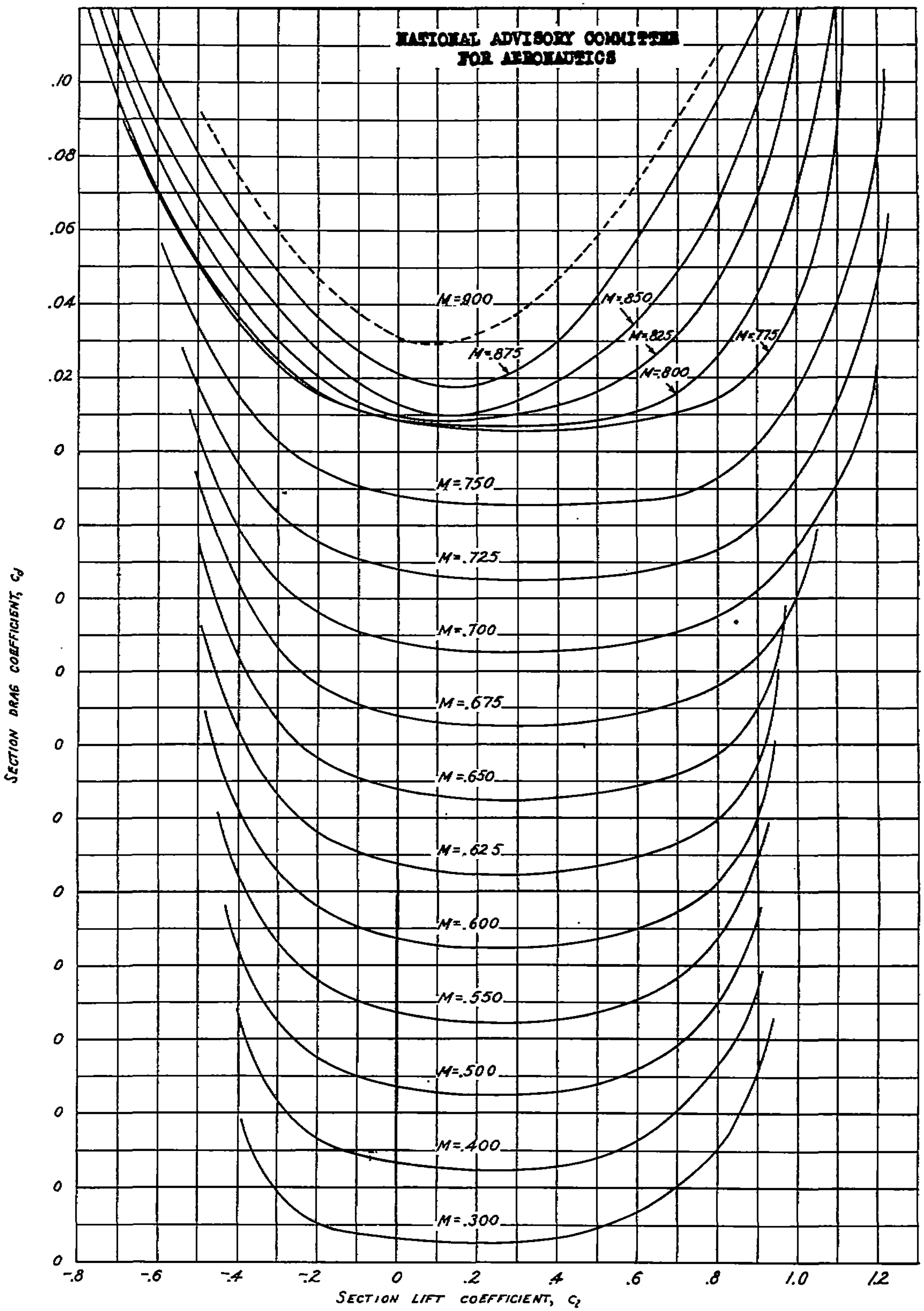


FIGURE 20. – VARIATION OF SECTION DRAG COEFFICIENT WITH LIFT COEFFICIENT FOR THE NACA 65-206 AIRFOIL.

[redacted]

M-1

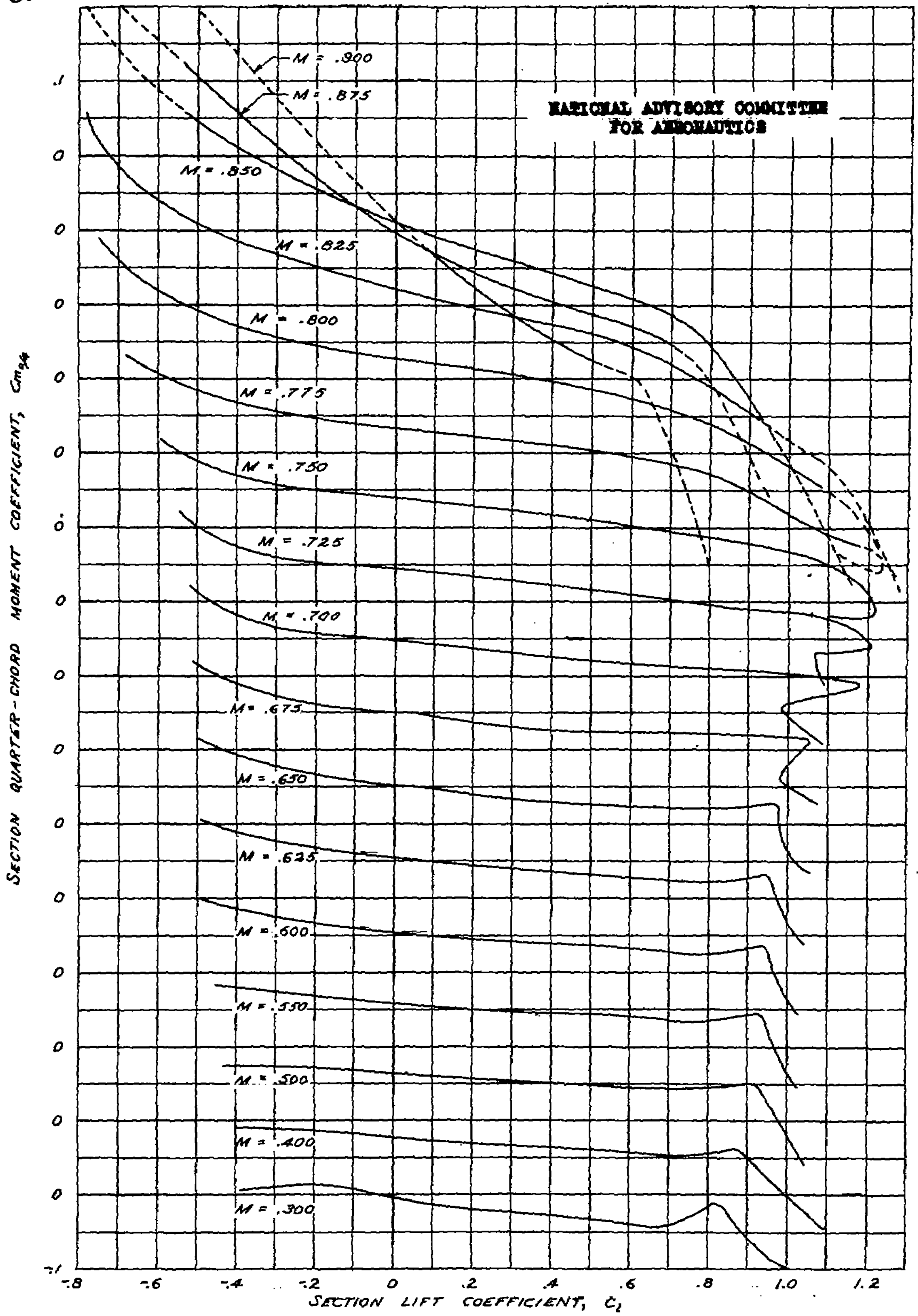


FIGURE 21.— VARIATION OF SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH LIFT COEFFICIENT FOR THE NACA 65-206 AIRFOIL.

[redacted]

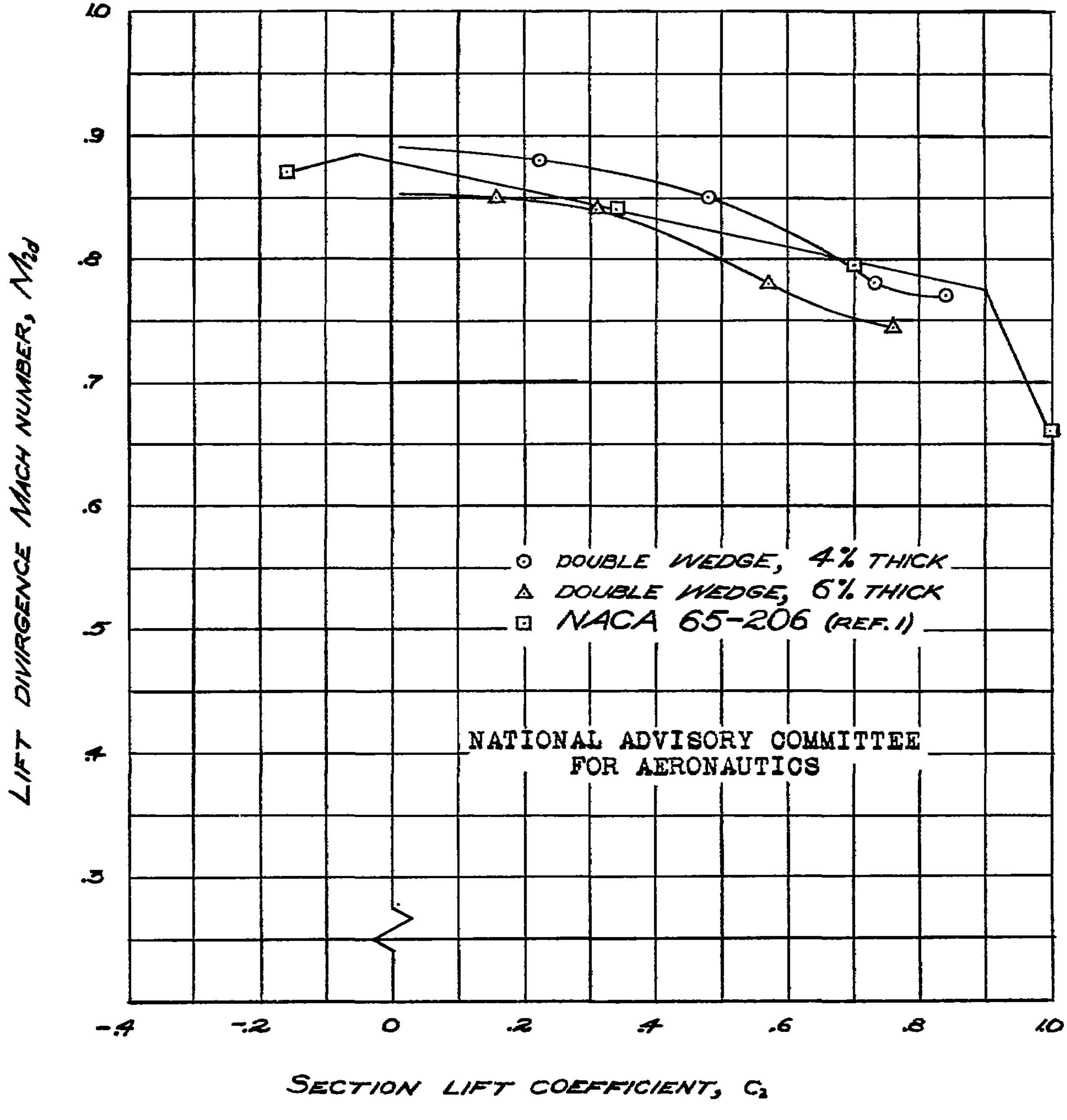


FIGURE 22.– COMPARISON OF THE VARIATIONS IN LIFT-DIVERGENCE MACH NUMBER WITH SECTION LIFT COEFFICIENT FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

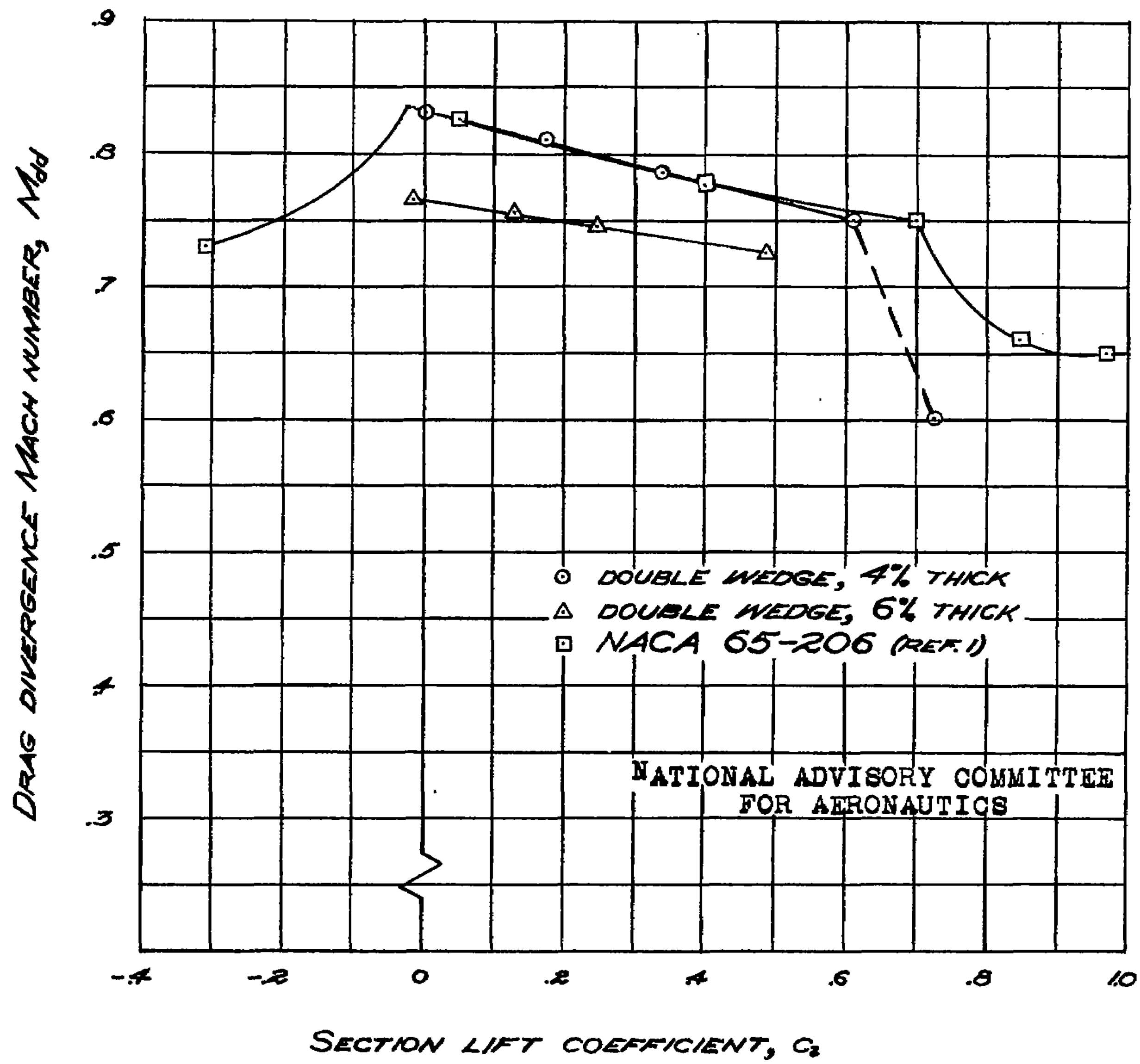


FIGURE 23.– COMPARISON OF THE VARIATIONS IN DRAG-DIVERGENCE MACH NUMBER WITH SECTION LIFT COEFFICIENT FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

[redacted]

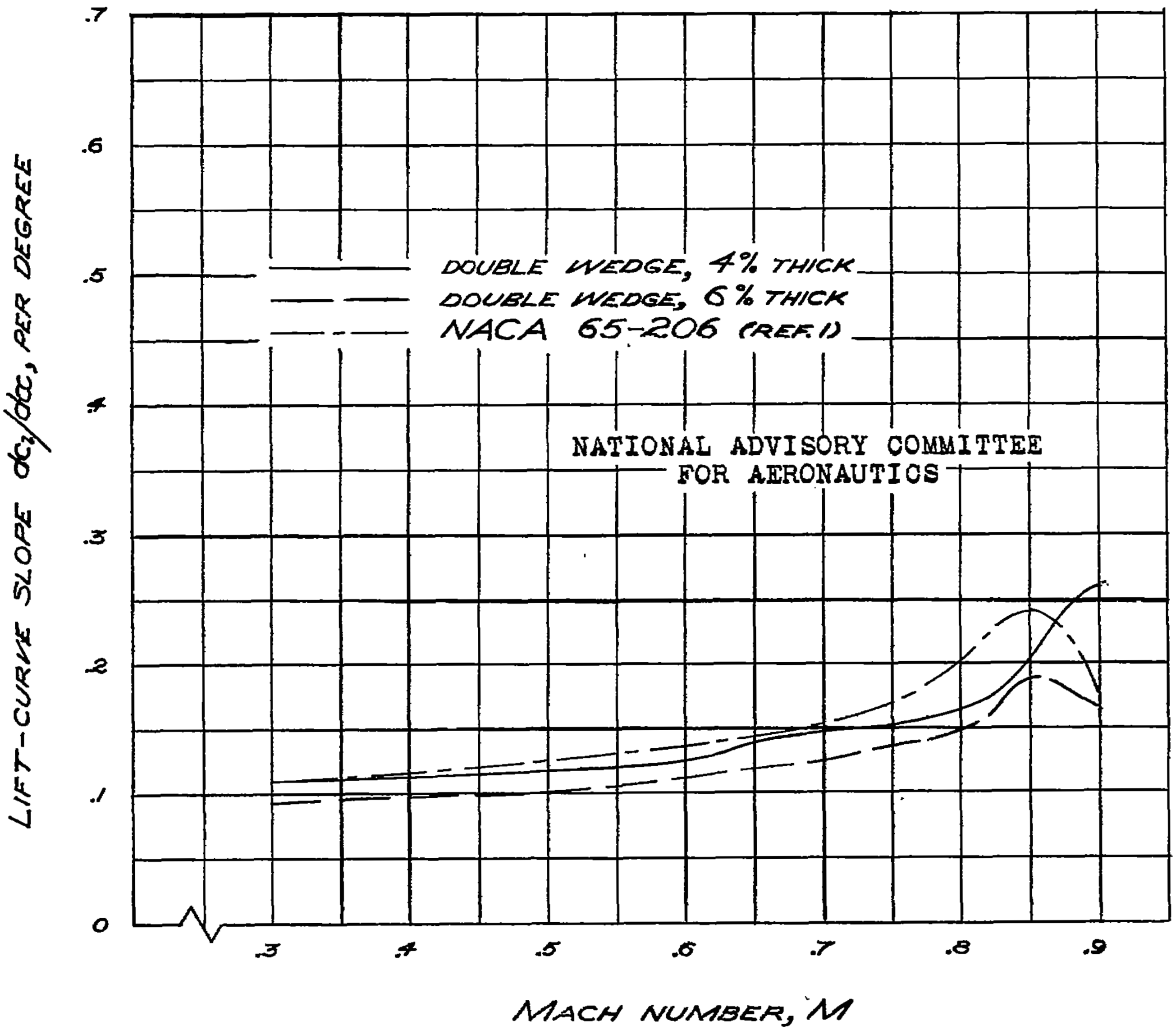


FIGURE 24.— COMPARISON OF THE VARIATIONS IN LIFT-CURVE SLOPE WITH MACH NUMBER AT A SECTION LIFT COEFFICIENT OF 0.1 FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

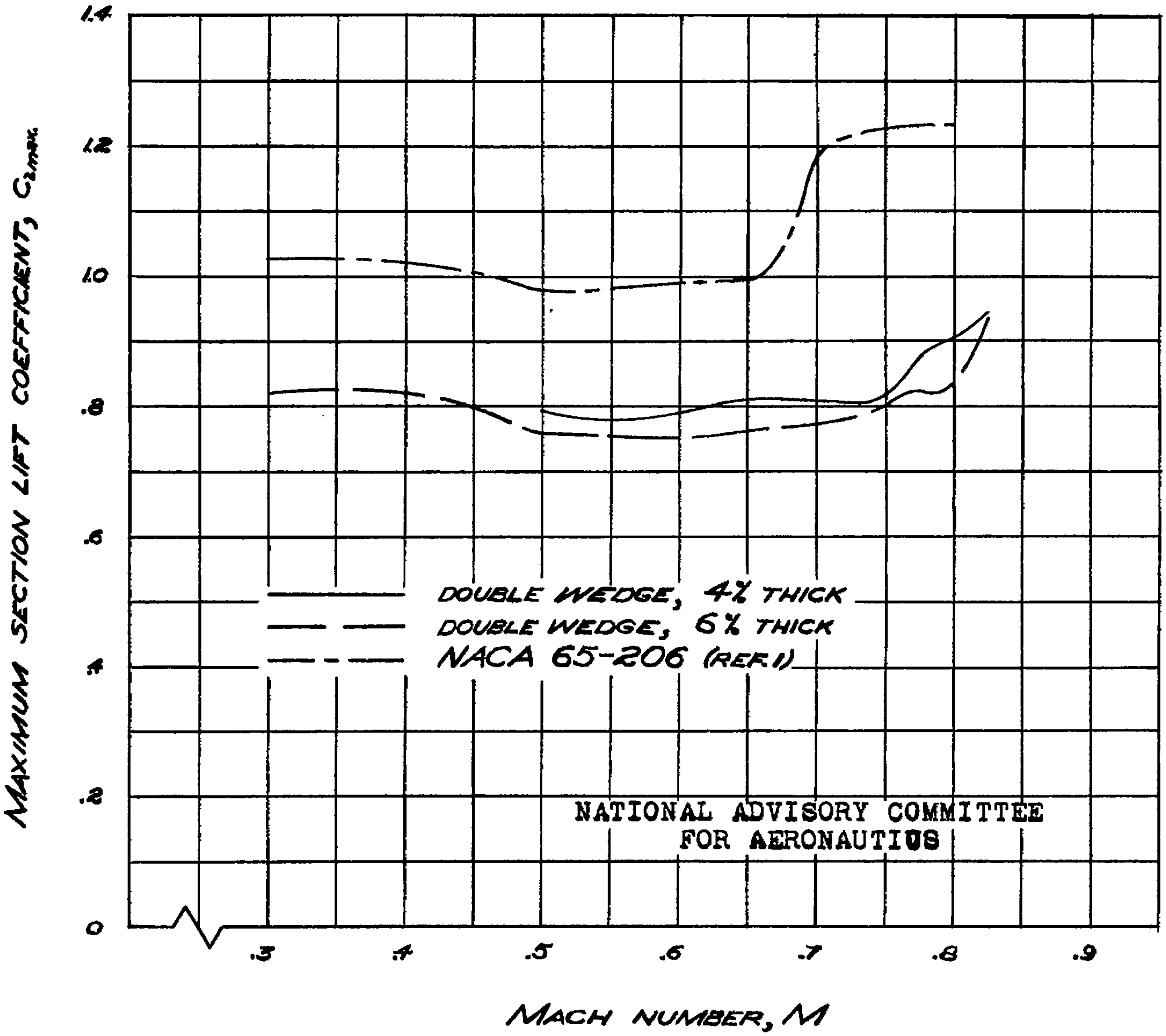


FIGURE 25. — COMPARISON OF THE VARIATIONS IN MAXIMUM SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

[redacted]

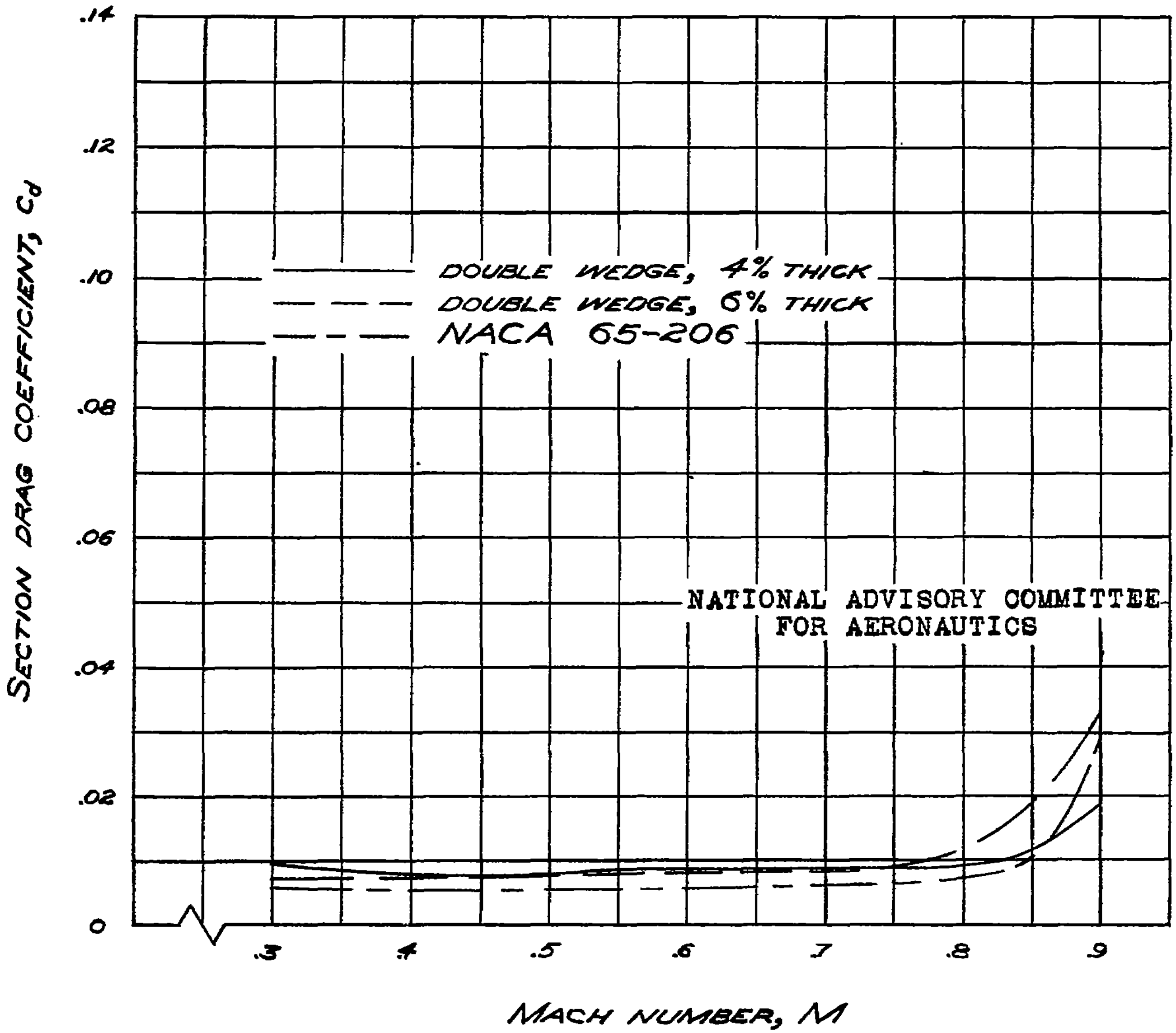


FIGURE 26.– COMPARISON OF THE VARIATIONS IN SECTION DRAG COEFFICIENT WITH MACH NUMBER AT A SECTION LIFT COEFFICIENT OF 0.1 FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

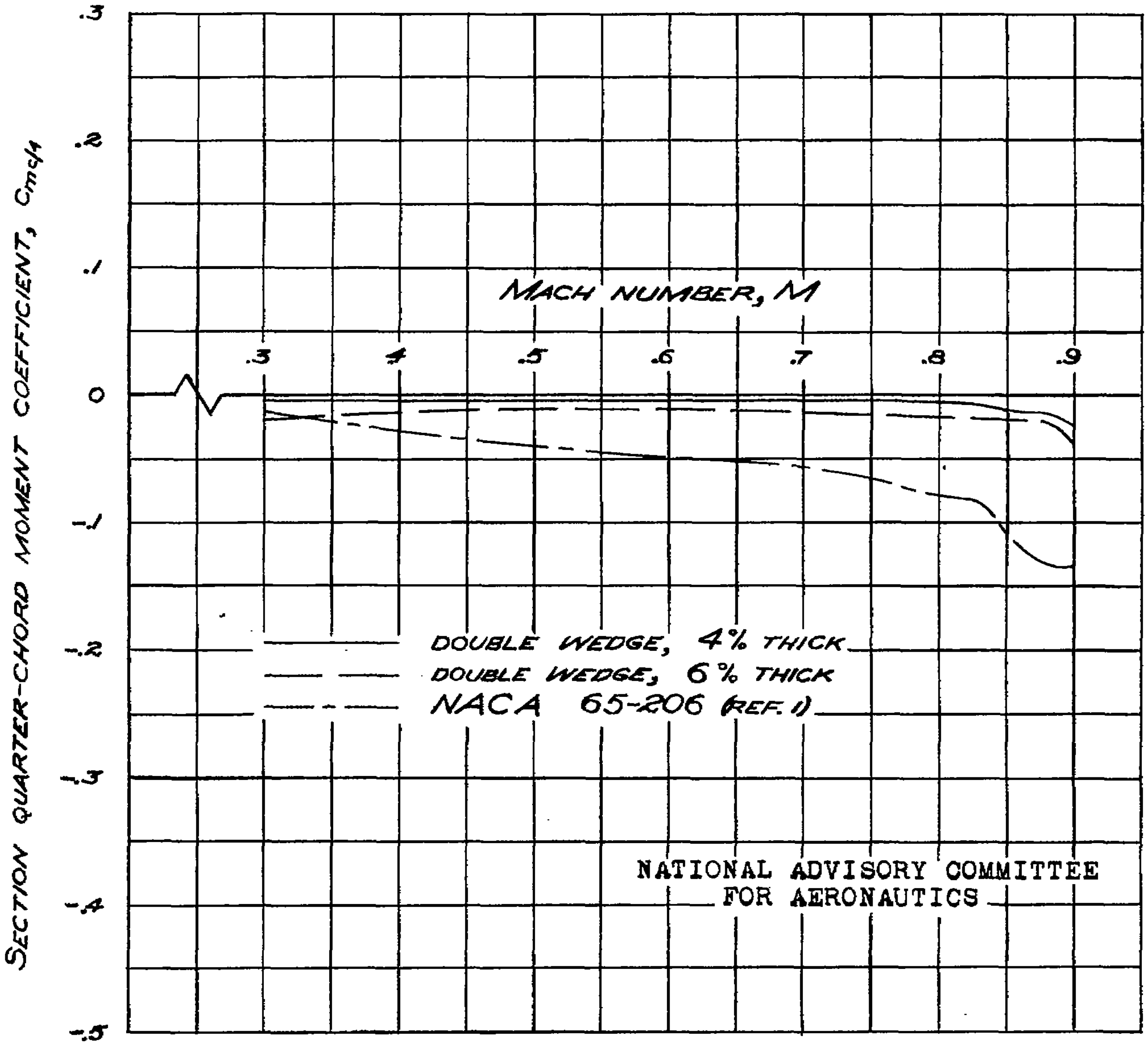


FIGURE 27. - COMPARISON OF THE VARIATIONS IN SECTION QUARTER-CHORD MOMENT COEFFICIENT WITH MACH NUMBER AT A LIFT COEFFICIENT OF 0.1 FOR TWO SYMMETRICAL DOUBLE-WEDGE AIRFOILS AND THE NACA 65-206 AIRFOIL.

[redacted]